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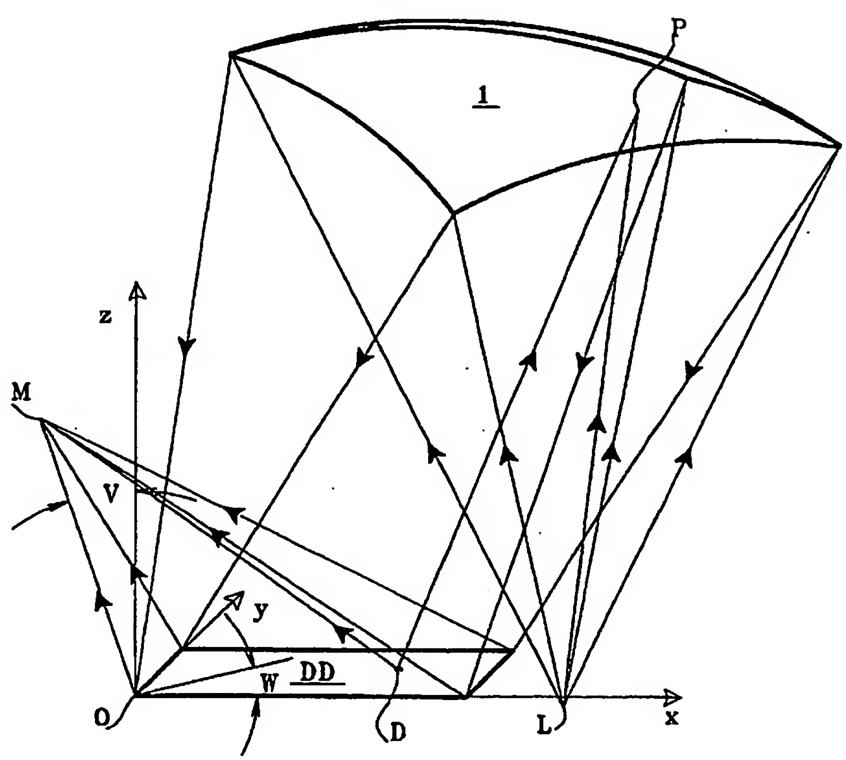
(57) Abstract

The invention relates to an illumination arrangement for a DMD-projector where the DMD is illuminated via a concave ellipsoidal or ellipsoid shaped mirror (1).



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ILLUMINATION ARRANGEMENT FOR PROJECTION WITH REFLECTIVE DISPLAYS

The invention relates to an illumination arrangement for projection with reflective displays. The invention especially relates to projection with DMD-type displays. DMD, Digital Mirroring Device, is described in the article "The Digital Micromirror Device (DMD) and its transition to HDTV" by J.M. Younce and D.W. Monk presented at The 13th International Display Research Conference, Strasbourg, August 31-September 3, 1993, pp 613-616. In more general terms, the invention relates to an illumination arrangement for all types of reflective SLMs (Spatial Light Modulators) where the DMD display constitutes a special case.

The invention thus relates to an illumination arrangement for DMD-projection that is designed in such a way that the light in the DMD on-mode is gathered into a projection lens, which is preferably situated so that its orthogonal projection toward the DMD plane will be located next to the DMD periphery or outside it.

The most commonly used illumination arrangements for DMD today use lens optics to gather the light to the DMD. Such optics are bulky and heavy, and will therefore obstruct the development of a DMD-based projector. It is, furthermore, not possible, using the already existing techniques, to make the reflecting light from the micromirrors in the on-mode gather in a concentrated area, i.e. there will be substantial pupil aberrations for the entrance pupil, which creates the need to use a smaller F-number for the lens and the necessity to therefore use many large lenses.

One of the purposes of the invention is to create a light and compact illumination arrangement that will make possible a rational and ergonomical construction of the projector. An other purpose of the invention is to create an illumination that largely eliminates pupil aberrations for the entrance pupil of the projection lens.

The first purpose of the invention is obtained by using the illumination arrangements described in the enclosed claims 1 through 3. The second purpose is attained with the enclosed claim 4.

Additional purposes are realised by the instructions for the illumination arrangement that are given in the enclosed dependent claims.

The fundamental principle for reaching the purposes of the invention is to use a concave ellipsoidal, or mainly ellipsoidal, mirror between the illumination source and the DMD. The illumination source is placed in one of the mirror's focal points, at which the entrance pupil will be in the mirror's other focal point where the light reaches after having been reflected against the DMD micromirror in the on-mode. The illumination source is placed by the edge of the DMD, or on the opposite side of the DMD in relationship to the concave mirror.

When an exact ellipsoidal mirror is used, there will be a great deal of pupil aberrations for the entrance pupil of the projection lens. The aberrations are due to the fact that the DMD micromirrors in the on-mode are not parallel to the DMD plane, but consist of collapsed, in relationship to the DMD plane, inclined mirrors. By manipulating the mirror's shape it is possible to largely eliminate the pupil aberrations.

A mirror that will meet the demand that light reflected against every DMD mirror is focused on the same point, is constituted so that for each DMD mirror there is only one corresponding mirror section. This mirror section's inclination is adjusted as to meet the demands. The surface can be calculated by proceeding from a certain DMD mirror and then deciding the surface of the corresponding mirror section. One then proceeds to the adjacent DMD mirror and decide the corresponding mirror section so that it will become adjacent to the previous mirror section etc. Since the DMD mirrors are extremely small, with a pitch of less than 20 micrometers, the mirror can be shaped as a slick surface.

The above described procedures of constructing the mirror's surface can be formalised thus.

Supposing that the DMD is placed in a system of co-ordinates with the axes x, y and z, with one corner of the DMD in the origin of co-ordinates and the DMD plane in the x, y-plane, that the projection lens' entrance pupil projected orthogonally against the DMD plane is situated closest to this corner or to an adjacent corner and that:

$\underline{P}$ is the position vector for a point with the co-ordinates (x,y,z)
$\underline{L}$ is the position vector for the position of the illumination source with the co-ordinates (x_4,y_4,z_4)
$\underline{M}$ is the position vector for the position of the entrance pupil with the co-ordinates (x_1,y_1,z_1)
$\underline{D}$ is the position vector for a point on the DMD with the co-ordinates $(x_2,y_2,0)$
$\underline{R} = \underline{M} - \underline{D}$
$\underline{S} = \underline{P} - \underline{D}$
$\underline{T} = \underline{L} - \underline{P}$
$\underline{\nu}$ = the micromirrors' unit normal with the co-ordinates (ν_x,ν_y,ν_z)
$\underline{\mu}$ = the mirror's unit normal with the co-ordinates (μ_x,μ_y,μ_z)
$\underline{C}$ is the vector $(\delta z/\delta x, \delta z/\delta y, -1)$

Then the following applies:

$$\underline{S} = a*(2*(\underline{\nu}*\underline{R})*\underline{\nu} - \underline{R}) \qquad (1)$$
$$\underline{T} = b*(\underline{S} - 2*(\underline{\mu}*\underline{S})*\underline{\mu}) \qquad (2)$$

$$\underline{C} = c * \underline{\mu} \qquad (3)$$

An elimination of the pupil aberrations can then be achieved for an ellipsoidal mirror that constitute the solution to the following system of differential equations:

$$\delta\underline{P}/\delta x_2 = \underline{Q}-\underline{S}*(\underline{Q}*\underline{C})/(\underline{S}*\underline{C}) \qquad (4)$$

$$\delta\underline{P}/\delta y_2 = \underline{A}-\underline{S}*(\underline{A}*\underline{C})/(\underline{S}*\underline{C}) \qquad (5)$$

where

$$\underline{Q} = (1+a,0,0) - 2*a*v_x*\underline{v} \qquad (6)$$

$$\underline{A} = (0,1+a,0) - 2*a*v_y*\underline{v} \qquad (7)$$

The distance between the DMD and the mirror together with the distance between the illumination source and the mirror is chosen large enough - considering the geometrical spread of the illumination source - to keep the F-number of the projection lens large enough.

The suitable procedure of computation is to chose proper positions for the illumination source and the entrance pupil of the projection lens together with the z-co-ordinate for that corner of the mirror from which a ray of light reaches the corner of the DMD where the origin of the system of co-ordinates is situated. The other co-ordinates for the mentioned corner are obtained in equation (1). The equations (2) and (3) render the vector $\underline{C}$. Equation (4) renders $\delta z/\delta x_2$ from which the z-value for the point on a mirror's surface that relates to a point on the DMD with the y_2-co-ordinate unchanged and $x_2 = x_2 + \Delta x_2$ whereupon the computations are repeated from equation (1) etc. until the whole surface and all the x_2-values have been run through. One then makes analogous computations in the y_2 direction with equation (5) instead of (4) and with the x_2 fixed ratio. One thus obtains mirror co-ordinates in the nodal points of a grid pattern on the surface of the mirror. It is also possible to, from the equations (4) through (7), obtain an analytical solution for the surface of the mirror. The surface obtained constitutes a concave mirror.

Partly to, considering the space, facilitate the design of the projection lens, partly to create as compact an illumination arrangement as possible, it is possible to, with a plane mirror between the DMD and the concave mirror, place the plane mirror so that the concave mirror ends up next to or right underneath the DMD. It is then suitable to, with an other plane mirror, deflect the light between the illumination source and the DMD so that the illumination source will end up next to or obliquely underneath the DMD. This way the area around the entrance pupil of the projection lens is uncovered, which partly facilitates the construction of the projection lens and partly makes possible the deflection of the projection-direction of the light for interchangeable left- and right-sided projection, which is described in the Swedish patent application number 9300958-7.

One easily realises that in a case where the unit normal v̲ of the micromirrors equals (0,0,1), the mirror will be ellipsoidal with one focal point in the illumination source L and the other focal point in the entrance pupil of the projection lens M. This is especially the case when, for instance, a reflective LCD is used instead of a DMD.

By changing the colour of the illumination source in coherence with the change of the information of the corresponding colour component in the DMD, colour pictures can be projected via a projection lens.

For the micromirrors' on-mode there are only three useful tilt-directions, namely the ones where the micromirror's upwardly directed surface normal in projection against the DMD has the directions 45, 135 and 315 degrees direction in the above mentioned system of co-ordinates. Of these directions, the two last are preferable, since they render the smallest amount of light absorption in the space below the micromirrors in the off-mode.

The above mentioned illumination source is primarily made up of an in the vicinity of an illumination focal point placed diffuser of the kind described in the Swedish patent application number 9300958-7.

The invention will in the following be described as an example with reference to the enclosed figures.

Fig 1. shows schematically how an illumination arrangement according to the invention is constructed.

Fig. 2 shows schematically the construction of a projection arrangement with an illumination arrangement according to the invention where the ray path has been folded together with plane mirrors.

Fig 1. shows schematically how an illumination arrangement with an ellipsoidal, or the ellipsoidal mirror 1, according to the invention is constructed. The illumination source L illuminates the mirror in such a way that a primarily even distribution of light is achieved on the DMD-device DD. The system of co-ordinates (x,y,z) has its origin of co-ordinates in O. The DMD-device's DD long side and front edge contain the x-axis. The micromirrors are in the on-mode tilted in such a way that the orthogonal projection of their upwardly directed unit normals have a direction W that is 135 degrees. The entrance pupil of the projection lens is situated by M. The ray that leaves a micromirror in O will have an angle V in relationship to the z-axis. This angle V is preferably 0 or positive, i.e. M has x- and y-co-ordinates that are preferably 0 or negative. Suitable values of the angle V are in the interval 0 trough 20 degrees. A ray of light from the illumination source L hits the mirror at the point P, where it is reflected to a micromirror D in the on-mode whereby the ray of light is reflected to the area M, which constitutes the centre of the entrance pupil in a projection lens. The orthogonal projection of the micromirrors' unit normals against the DMD plane will in the off-mode have a direction of 45 degrees and thereby will

the light in the off-mode be reflected to an area with a negative y-value. This area, that should be black and well ventilated, will be situated at an adequate distance from the pupil area M. An analogous case is obtained when the micromirrors' unit normals' orthogonal projection against the DMD in the on-mode has the location 45 degrees. In the off-mode, however, the light will be reflected to an area with a positive y-co-ordinate. If one chooses to locate the micromirrors so that they in the on-mode, against the DMD-plane, orthogonal projection by the micromirrors' unit normals has the direction W 45 degrees, there will be greater problems with more of the light ending up underneath the micromirrors when they are in the off-mode, which is partly owing to the fact that there are greater angles of incidence for the light against the DMD-device's DD-plane, partly to the fact that the micromirrors in the off-mode then will have a location in relationship to the incident light that is unfavourable.

Fig. 2 shows schematically the construction of a projection arrangement with an illumination arrangement according to the invention where the ray path have been folded together with plane mirrors 2 and 3. The DMD-device DD shows in the figure with the origin O for the system of co-ordinates the farthest away from the viewer, while its short side is the closest to the viewer. The light from the illumination source L is reflected first against the plane mirror 2, then against the ellipsoidal or the ellipsoid shaped mirror 1 and then against the plane mirror 3. After that the light reaches the DMD-device DD, from where the mirrors in the on-mode direct the light toward the projection lens' 4 entrance pupil M. The object 5 signifies a deflection mirror that deflects the light to the side, upwards and downwards. It is possible to, with the help of a mirror-coated triangular prism, change between right- and leftsided projection in the way that has been described in the Swedish patent application number 9300958-7.

Claims:

1. An illumination arrangement for projection with reflective displays *characterised by* an in effect nearly point shaped source of light (L) and an ellipsoid shaped mirror (1) for illumination from the source of light against a reflective display (DD), whereby the mirror (1) is shaped so that every part of the display (DD) is illuminated at an angle which allows for its reflected light to hit an almost point-shaped area (M), which can be arranged as the position of an entrance pupil of a projection lens (4).

2. An illumination arrangement according to claim 1, *characterised by* the reflective display (DD) being made out of a number of tiltable micromirrors, whereby the mirror (1) is shaped so that each micromirror in its on-mode is illuminated at an angle which allows for its reflected light to hit a mainly point-shaped area (M), which is arrangeable as the position of an entrance pupil of a projection lens (4).

3. An illumination arrangement according to claim 2, *characterised by* the reflective display being of the DMD-type.

4. An illumination arrangement according to any of the claims 2 or 3, *characterised by* the mirror (1) for each micromirror (D) having a surface section (P), which from the source of light (L) reflects light against it, so that a 1-1 correspondence takes place between every micromirror and such a surface section, besides which the against each other adjacent surface sections are joined smoothly together.

5. An illumination arrangement according to claim 4, *characterised by* the mirror (1) being designed in such a way that there is a point in the source of light of the kind that all the light rays that are reflected via the mirror (1) and the reflective display's (DD) mirrors (D) in the on-mode essentially hit the same spot in the area (M), which can be arranged as the position of an entrance pupil of a projection lens (4).

6. An illumination arrangement according to any of the claims 1 or 2, *characterised by* the mirror (1) mainly being shaped as an ellipsoidal mirror with one focal point mainly coinciding with the illumination source (L).

7. An illumination arrangement according to claim 5, *characterised by* the mirror (1) primarily being shaped so that if the DMD-device (DD) is situated in a system of co-ordinates with the axes x, y and z with one corner of the DMD-device in the origin in the system of co-ordinates and the plane of the DMD-device in the x,y-plane, that the entrance pupil of the projection lens projected orthogonally against the DMD plane is situated closest to this corner or an adjacent corner, that

$\underline{P}$ is the position vector for a point with the co-ordinates (x,y,z)
$\underline{L}$ is the position vector for the position of the illumination source with the co-ordinates (x_4,y_4,z_4)
$\underline{M}$ is the position vector for the position of the entrance pupil with the co-ordinates (x_1,y_1,z_1)

$\underline{D}$ is the position vector for a point (D) on the reflective display with the co-ordinates $(x_2,y_2,0)$

$\underline{R} = \underline{M} - \underline{D}$

$\underline{S} = \underline{P} - \underline{D}$

$\underline{T} = \underline{L} - \underline{P}$

$\underline{\nu}$ = the micromirrors' unit normal with the co-ordinates (ν_x,ν_y,ν_z)

$\underline{\mu}$ = the mirror's unit normal with the co-ordinates (μ_x,μ_y,μ_z)

$\underline{C}$ is the vector $(\delta z/\delta x,\delta z/\delta y,-1)$

that the vector $\underline{C}$ can be obtained from the equations

$$\underline{S} = a*(2*(\underline{\nu}*\underline{R})*\underline{\nu} - \underline{R}) \qquad (1)$$

$$\underline{T} = b*(\underline{S} - 2*(\underline{\mu}*\underline{S})*\underline{\mu}) \qquad (2)$$

$$\underline{C} = c*\underline{\mu} \qquad (3)$$

that the mirror's (1) shape can be decided by using the differential equations

$$\delta\underline{P}/\delta x_2 = \underline{Q}-\underline{S}*(\underline{Q}*\underline{C})/(\underline{S}*\underline{C}) \qquad (4)$$

$$\delta\underline{P}/\delta y_2 = \underline{A}-\underline{S}*(\underline{A}*\underline{C})/(\underline{S}*\underline{C}) \qquad (5)$$

where

$$\underline{Q} = (1+a,0,0) - 2*a*\nu_x*\underline{\nu} \qquad (6)$$

$$\underline{A} = (0,1+a,0) - 2*a*\nu_y*\underline{\nu} \qquad (7)$$

8. An illumination arrangement according to any of the claims 1 through 7, *characterised by* the ray path between the reflective display (DD) and the ellipsoidal mirror (1) is deflected with a plane mirror (3) so that the ellipsoid shaped mirror (1) ends up on the side of the reflective display (DD).

9. An illumination arrangement according to any of the claims 1 through 8, *characterised by* the ray path between the ellipsoidal or ellipsoid shaped mirror (1) and the illumination source (L) is deflected by a plane mirror (2).

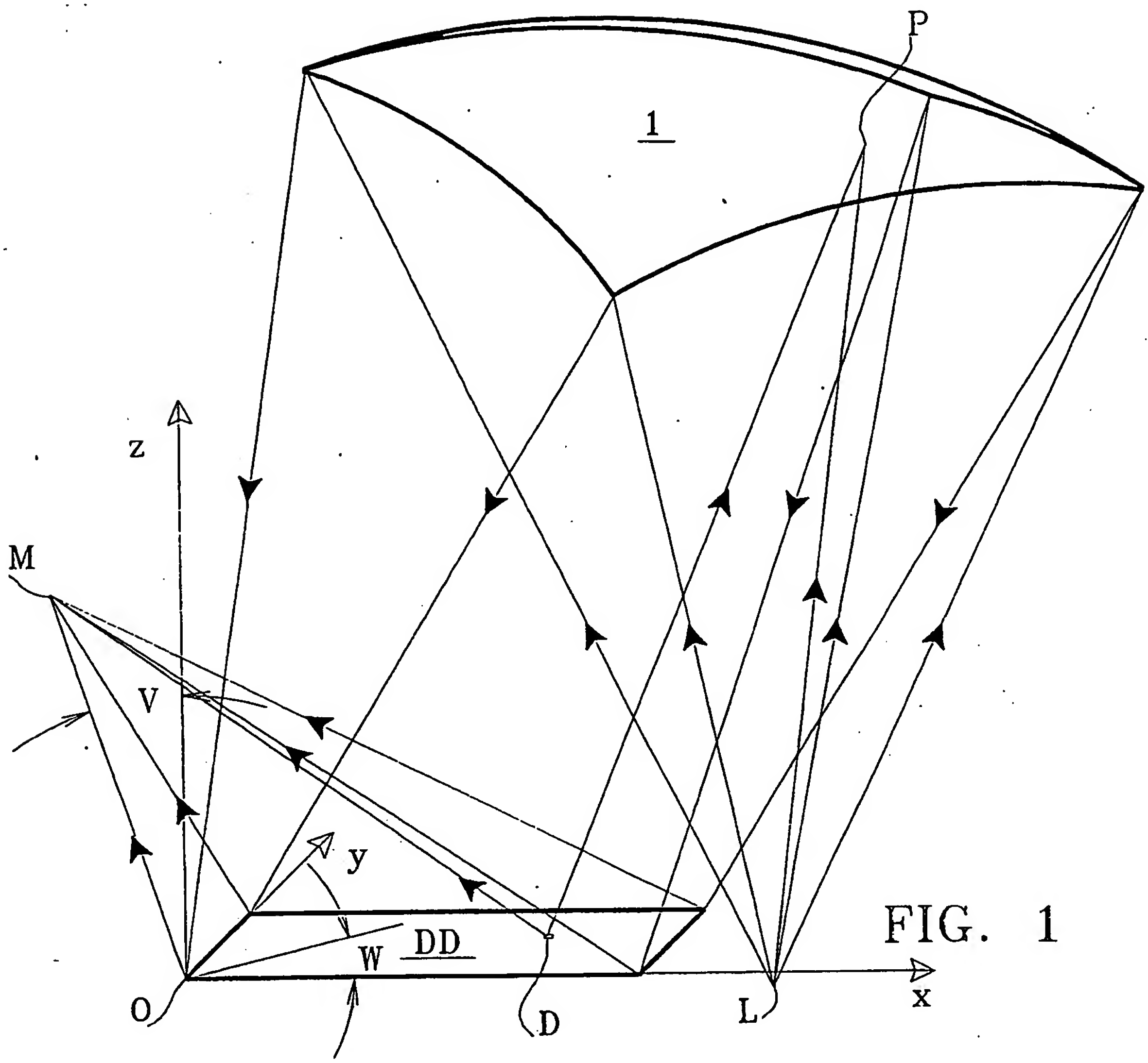

FIG. 1

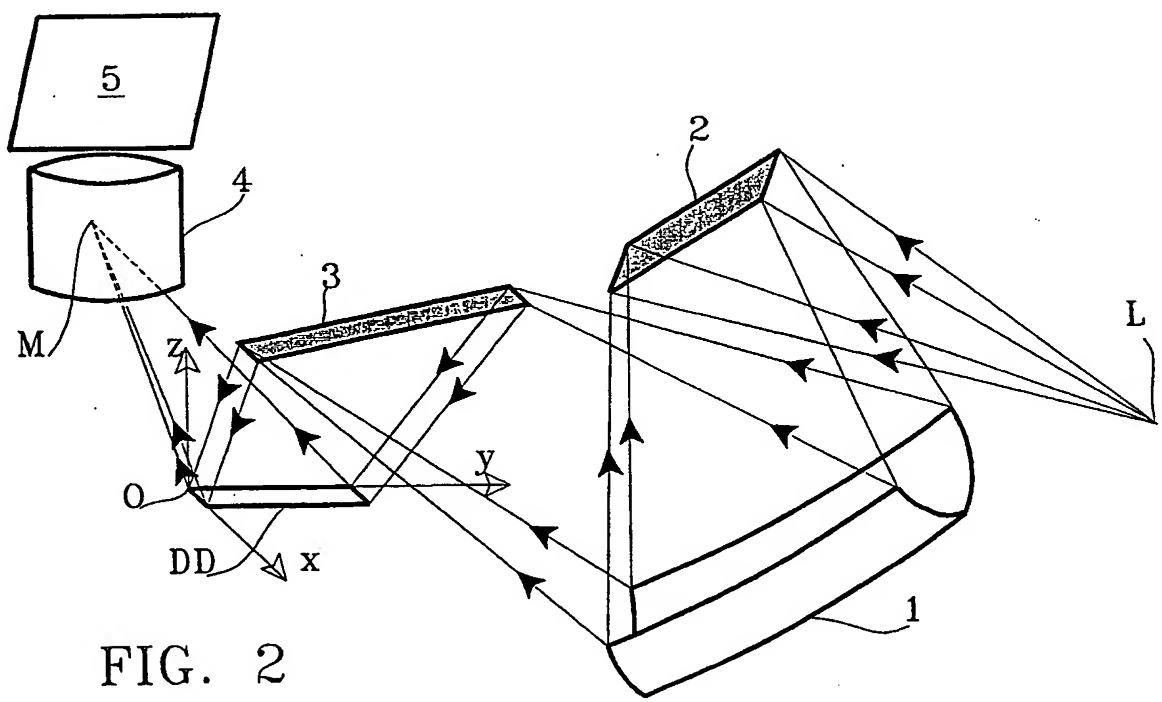

FIG. 2

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE 95/00769

A. CLASSIFICATION OF SUBJECT MATTER

IPC6: G03B 21/20, G02B 27/18 // G03B 21/00, G02B 19/00, G02B 26/08
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Minimum documentation searched (classification system followed by classification symbols)

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Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

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CLAIMS, WPI

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EP 0640858 A2 (PHILIPS ELECTRONICS N.V.), 1 March 1995 (01.03.95), abstract --	1-9
A	EP 0657760 A1 (FLORENCE, JAMES ET AL), 14 June 1995 (14.06.95), abstract --	1-9
A	US 5105299 A (ANDERSON ET AL), 14 April 1992 (14.04.92), abstract --	1-9
A	US 5420655 A (SHIMIZU), 30 May 1995 (30.05.95), abstract -- --------	1-9

☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

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INTERNATIONAL SEARCH REPORT
Information on patent family members

05/01/96

International application No.
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Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP-A2- 0640858	01/03/95	NONE	
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